Regional correlations of COVID-19 in Spain

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Abstract

This paper analyzes the correlation between confirmed cases of COVID-19 and several geographic, meteorological and socioeconomic variables at the province level in Spain. The results indicate that there is a strong and robust negative relationship between average temperature and the rate of cases of COVID-19. The explanatory power of other geographic and socioeconomic variables is much lower. A parsimonious model including population density and temperature is able to explain 67% of variation in cases of COVID. However, the results are inconclusive regarding the existence of a relationship between *changes* in temperature and *changes* in COVID cases, casting doubts on the existence of a negative link between temperature and the spread of the virus.

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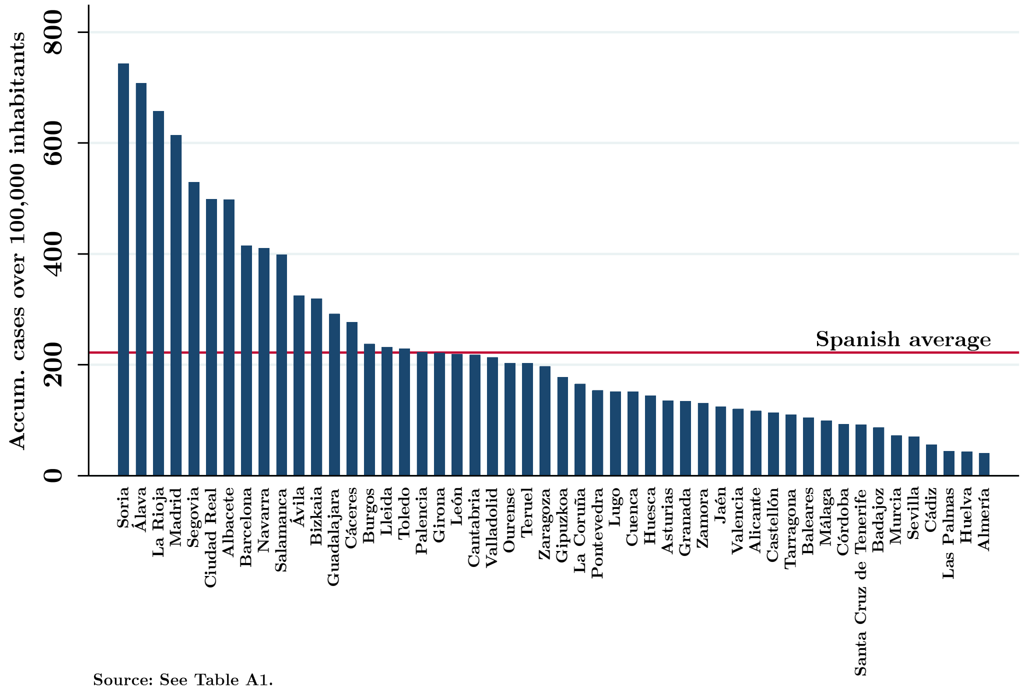
1. Introduction

This paper analyzes the correlation between confirmed cases of COVID-19 and several geographic, meteorological and socioeconomic variables at the province level in Spain. The incidence of COVID-19 greatly varies across the Spanish provinces. Based on the data as of April 1, the accumulated case rate per 100,000 inhabitants in Soria, the province with the highest incidence, is 18 times higher than that of Almería, the one with the lowest incidence. As of May 1, the ratio between the province with the highest and lowest incidence had increased to 31. Figure 1 shows the value of the accumulated case rate for each province, while Map 1 represents it geographically.

Given these large provincial differences, it is worth asking what factors can explain them. Are the provinces with the highest COVID-19 rate the most populated? The ones that receive more tourists? The coldest? The objective of this paper is to analyze the relationship at the provincial level between the incidence of COVID-19 and several meteorological, geographic and socioeconomic factors.[1] It goes without saying that what I show below are correlations and I will limit myself to interpret them as such.

Figure 1: Accumulated cases of COVID-19 across provinces on April 1

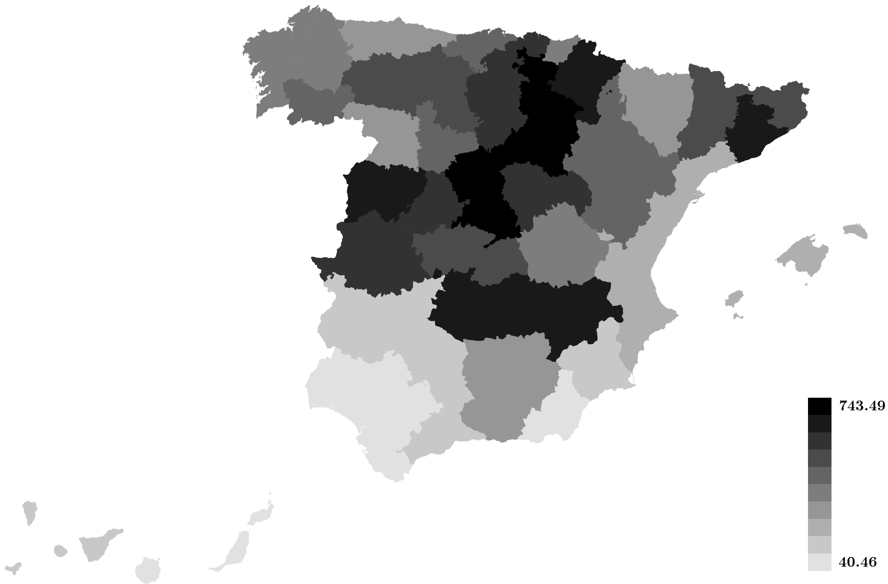


Source: See Table A1.

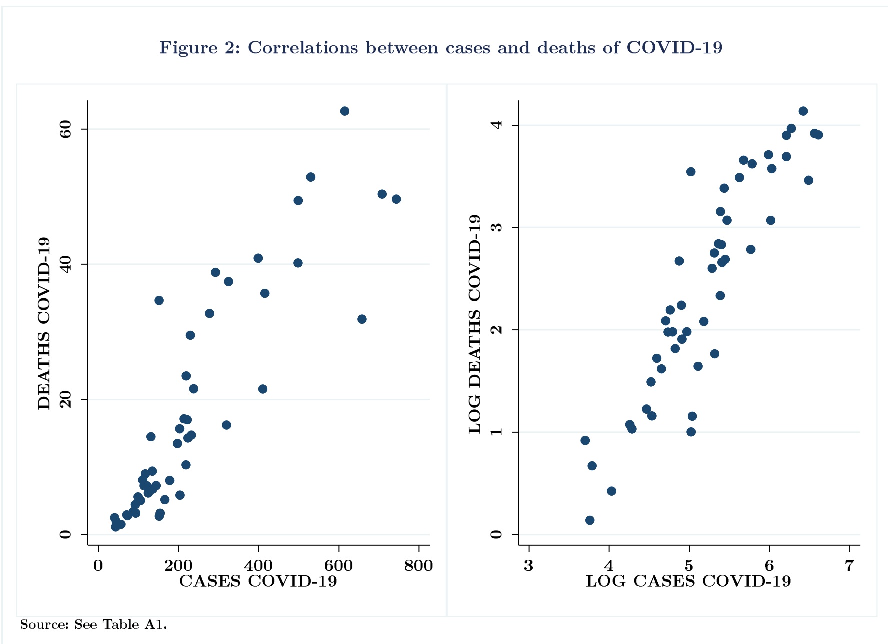
[1] See Orea and Álvarez (2020) for a study on the effect of confinement measures on the spread of coronavirus in Spain.

The correlation between cases and deaths of COVID-19 is high, with p= 0.88 or 0.90 in logs. Figure 2 shows the relationship between both variables. The rest of the paper uses the logarithmic transformation as its distribution is closer to a normal one, avoiding the influence of high values (see Figure 3).

Map 1: Accumulated cases of COVID-19 across provinces on April 1

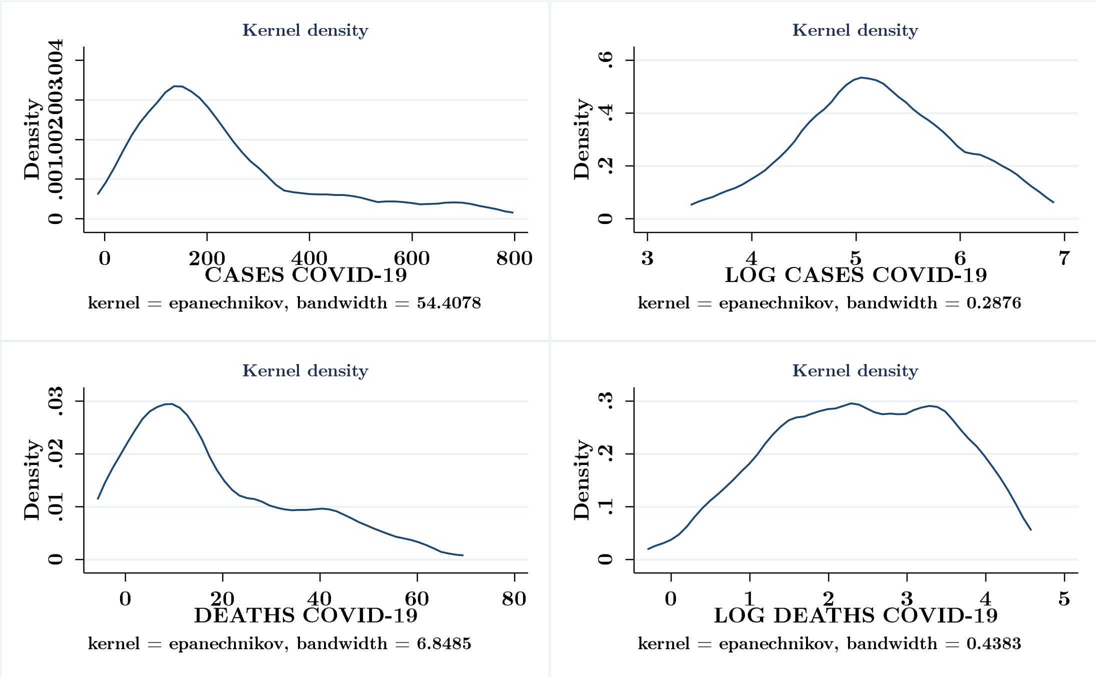


Source: See Table A1.



Source: See Table A1.

Figure 3: Distribution of the variables cases and deaths of COVID-19 per 100.000 inhabitants



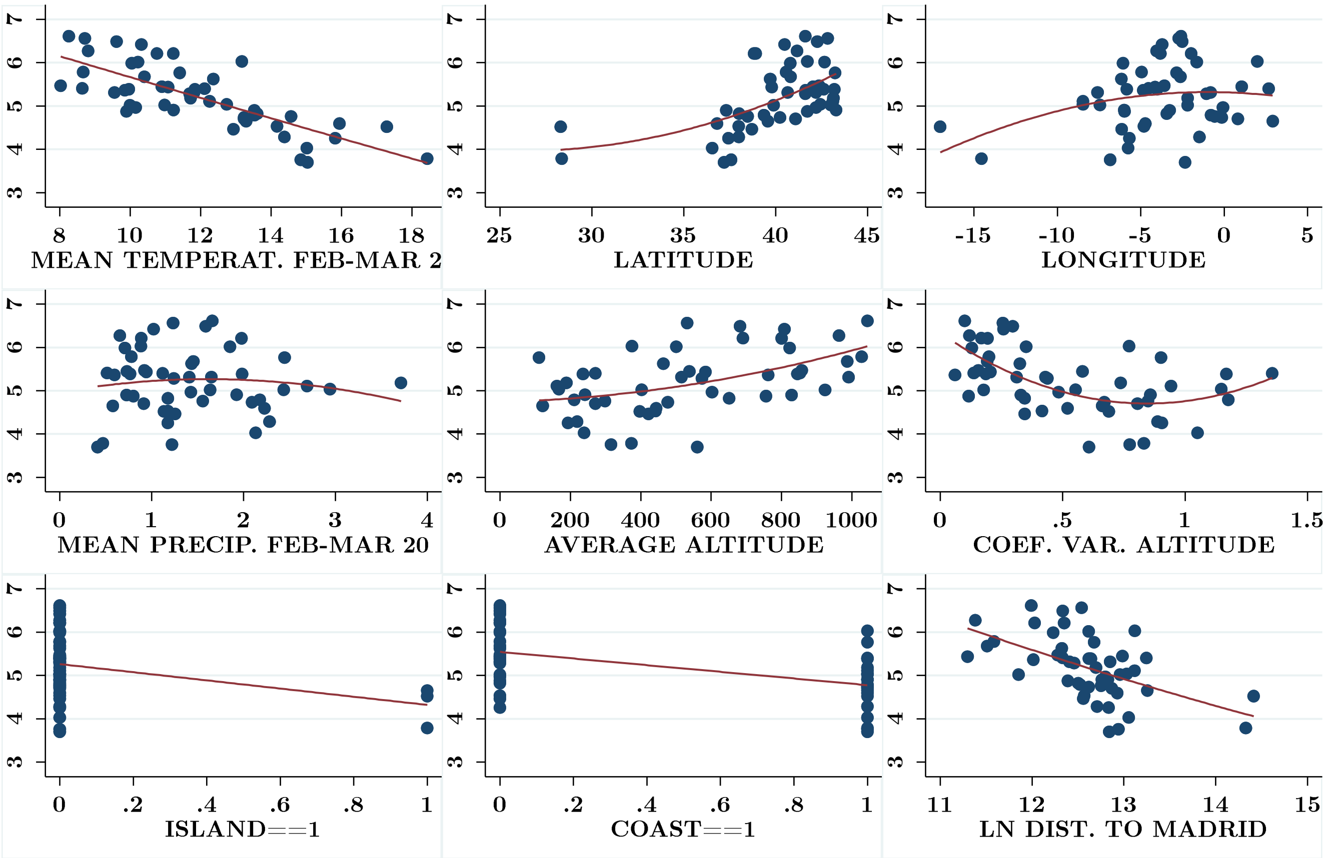
Source: See Table A1.

2. Analysis

2.1. Geographic and meteorological variables

Figure 4 depicts the relationship between COVID-19 cases on April 1 and the following geographic and meteorological variables: latitude, longitude, average temperature and rainfall during February and March of 2020, average altitude, coefficient of variation of altitude, being an island, being a coastal province, and (log) distance to Madrid. It can be seen that the northernmost and coldest provinces, those with a higher average altitude, flatter, landlocked and closer to Madrid have on average a higher incidence of COVID-19. The correlation is particularly strong in the case of temperature. Table 1, which reports the coefficients from these bivariate relationships, shows that the R^2 associated with temperature is twice that of the variable that follows it in explanatory power. The average temperature recorded during February and March of this year explains 59% of the variation in the rate of cases of COVID. Another interesting relationship is the one observed with distance to Madrid. Provinces closer to Madrid have, on average, a higher rate of accumulated cases -although this correlation disappears when controlling for temperature.

Figure 4: Correlations between the rate of COVID-19 cases and several geo-climatic variables



Notes: The variable on the Y axis is always the log of accumulated cases of COVID19/100000 inhab. on April 1. Madrid is omitted when using distance to Madrid. Sources: See Table A1

The negative correlation between COVID-19 cases and temperature is consistent with other observational studies (for instance, Coccia, 2020; Qi et al., 2020, Wang et al., 2020)[2], but is this provincial correlation robust when other geographic variables are taken into account? Column 10 of Table 1 shows that this is, in fact, the case: when all the variables are included together, only temperature is statistically significant (distance to Madrid is marginally significant). Column 11 removes latitude and longitude as they (particularly latitude) are correlated with other regressors and do not capture any specific geographic or climatic factor by themselves -beyond obviously the northward and eastward location. Only temperature and distance to Madrid are statistically significant.

[2] Some preliminary results at the regional (autonomous community) level in Spain also suggest a negative relationship between temperature and cases of COVID-19 (Ministerio de Ciencia, 2020).

The two previous regressions contain some variables related to each other, generating multicollinearity. An alternative way to choose the variables to include is through the *stepwise* method, which progressively selects a model based on the statistical significance of the variables. This method leads to a model that only includes temperature, which suggests that it is the most relevant factor (column 12). If we exclude the Canary Islands, which is an overseas territory that may behave differently, the model also includes distance to Madrid.[3]

Table 2 focuses on the relationship between temperature and the rate of COVID-19 cases. Columns 1 to 9 show that the coefficient is very stable when including the other geographic variables one by one. The negative relationship is not affected either when Canarias and Madrid are excluded in columns 10 and 11. The introduction of a set of 17 dummy variables, one for each autonomous community in Spain, does not negate the effect of temperature.

Table 3 assesses the robustness of the negative correlation between distance to Madrid and COVID-19. Column 1 shows the bivariate relationship, while the next column excludes Madrid itself (resulting in the same regression as in column 9, Table 1). Column 3 excludes the Canary Islands and column 4 further excludes Madrid. The coefficient remains large and highly statistically significant to these changes. However, if we add temperature to the last model, distance to Madrid becomes insignificant.

2.2. Socioeconomic variables

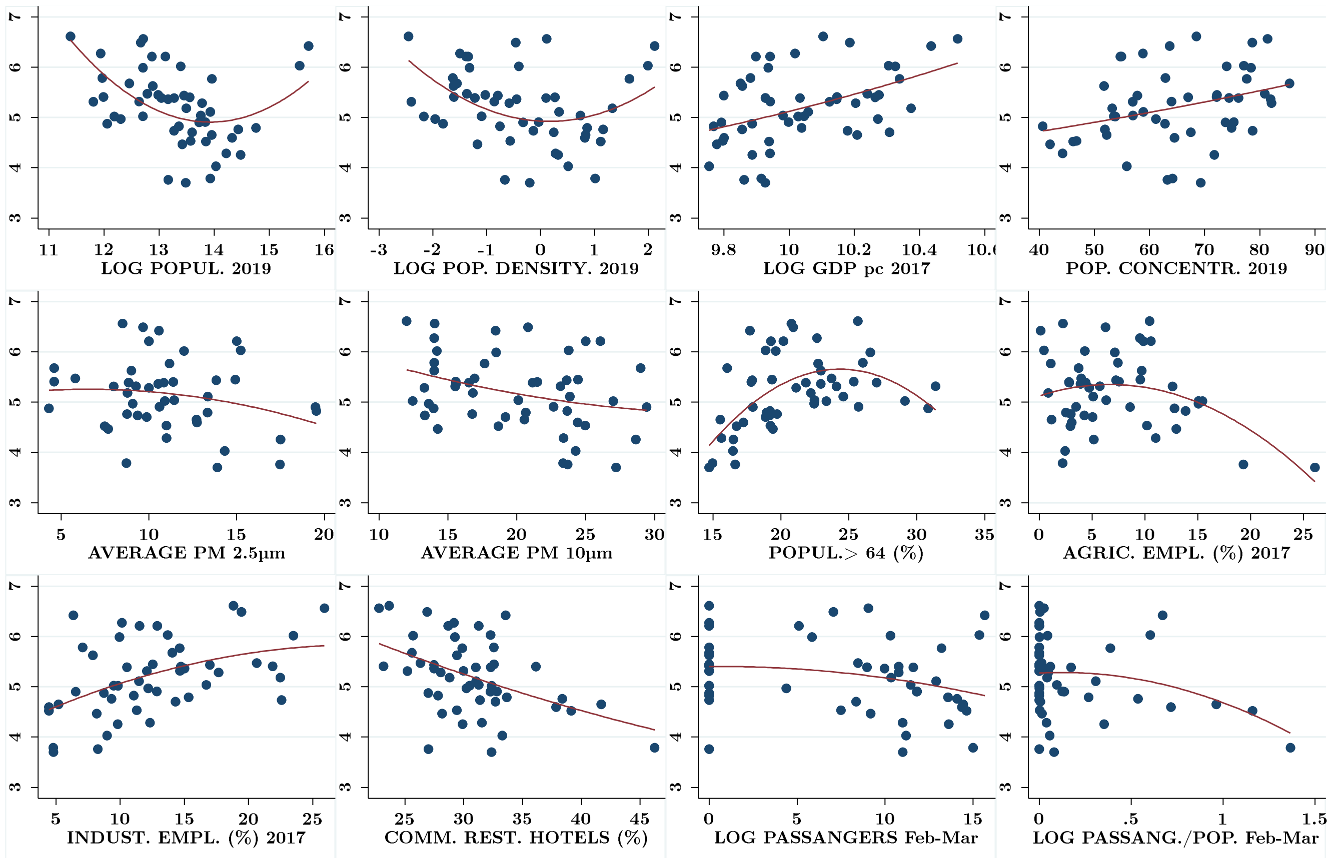
Figure 5 depicts the relationship between the rate of COVID-19 cases and a set of socio-economic variables, namely: total population and population density in 2019 (both in log.), GDP per capita in 2017 (log.), population concentration (the percentage of the population living in the most populous 10% of the territory), air pollution in 2018 (measured as the annual average of particles less than 10 and 2.5 μm), percentage of population older than 64 years in 2019, percentage of workers in different branches of activity in 2017 (agriculture, industry and commerce-restaurants-hotels)[4], number of airline passengers in February and March 2020 and the same number relative to the

[3] The forward and backward selection estimations render the same results.

[4] The variable measuring the percentage of employment in commerce, restaurants and hotels refers to the activity branches G to J according to the Statistical Classification of Economic Activities in the European Community (NACE).

province population (both in log.).[5] Table 4 reports the coefficients on the linear relationship between cases of COVID-19 and the twelve variables included in the figure. First, it is interesting to note that correlations are weaker than in the case of geographic and meteorological variables. In some cases, the sign of the correlation is counter-intuitive, although it must be borne in mind that they are bivariate relationships and it is difficult to interpret them on their own, without considering the effect of other factors.

Figure 5: Correlations between the rate of COVID-19 cases and several socioeconomic variables



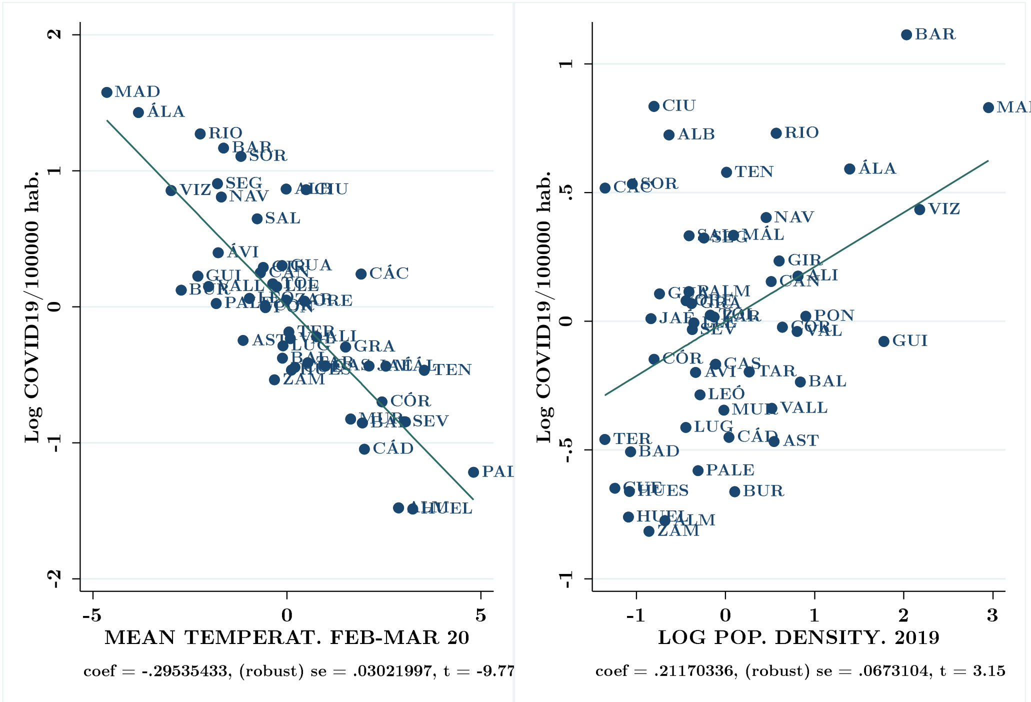
Notes: The variable on the Y axis is always the log of accumulated cases of COVID19/100000 inhab. on April 1.
Sources: See Table A1.

Column 1 of Table 5 includes all the socioeconomic controls together, where only GDP per capita enters with a statistically significant coefficient. To avoid multicollinearity problems, I use again the *stepwise* method, which in column 2 leads to a model with GDP per capita and the percentage of population above 64 carrying positive coefficients, and

[5] I have also calculated the following indicators: population density of the 10% most populated of the territory, log GDP, and log GDP intensity (that is, GDP/surface area). However, these variables are not used in the analysis because they are highly correlated with population density and total population.

the percentage of employment in commerce, restaurants and hotels carrying a negative one.[6] Column 3 reruns the same regression as in column 1 but adding temperature as a basic control. Interestingly, the latter enters with a large and statistically significant coefficients while the only (marginally) significant coefficient among the socioeconomic variables is population density. Finally, column 4 runs the *stepwise* method including temperature as a compulsory control, rendering a parsimonious model with population density that explains 67% of the variation in COVID-19 cases. The conditional relationships (from this last model) of the rate of COVID cases with temperature and population density are represented in Figure 6.

Figure 6: Conditional relationships of COVID-19 cases with temperature and population density



2.3. Cases of COVID-19 before the confinement

The results so far correspond to the rate of COVID-19 cases on April 1 as a benchmark date. Therefore, the above correlations can be interpreted as the cross-sectional relationship between each factor and the reception and spread of the virus during the months of February and March. However, a strict confinement was enacted by the Spanish government -together with the establishment of the state of emergency- on

[6] The forward and backward selection estimations render the same results.

March 14 (coming into force the next day), and this measure may have affected the correlations reported above. Therefore, it is relevant to redo the analysis using the rate of cases on March 15. The correlation of the rate of COVID-19 cases between April 1 and March 15 is 0.71, which is a relatively high value but leaves room for changes among provinces. For this analysis, I calculate the average temperature and rainfall for the period from February 1 to March 15.

Tables 6 to 10 provide the results. The explanatory power of the geographic and socioeconomic variables is in general significantly lower. Particularly, the coefficient on temperature is smaller in size and less robust, losing importance against distance to Madrid. These different results may be because i) it is more difficult to explain the incidence of COVID-19 at an earlier stage of the epidemic, ii) the influence of the confinement measures, or iii) more measurement errors in March 15 than in April 1.

2.4. Changes in the rate of COVID-19 cases

I turn now to analyze the correlations with changes in COVID-19 cases by using as dependent variable the difference in (the log of) the rate of cases between two dates. This difference actually means the rate of new cases accumulated during the specified period. Table 11 reports the results. In most of the regressions the sample consists of 46 observations as the four Galician provinces have missing data. On the left (Panel A), temperature is included without lags, while on the right (Panel B) temperature is lagged 10 days to allow for an incubation period of coronavirus. All regressions include the log of COVID-19 cases at the beginning of each period since the increase in cases is expected to depend on its initial value, that is, to take into account the dynamics of the epidemic.

The top part of the table analyzes the relationship between changes in COVID cases (i.e., new cases) during a specific period and average temperature during the same period. I consider four periods: May 1 – April 1; April 1 – March 15; April 15 – April 1; May 1 – April 15. Remarkably, the negative relationship between changes in COVID-19 cases and temperature is very robust. Considering column 1 in Panel A, provinces that have experienced a higher average temperature during April have had a lower rate of new COVID cases. More specifically, one Celsius degree increase in temperature is associated with a 13% decrease in the rate of new cases (i.e., $e^{-0.136}$-1).

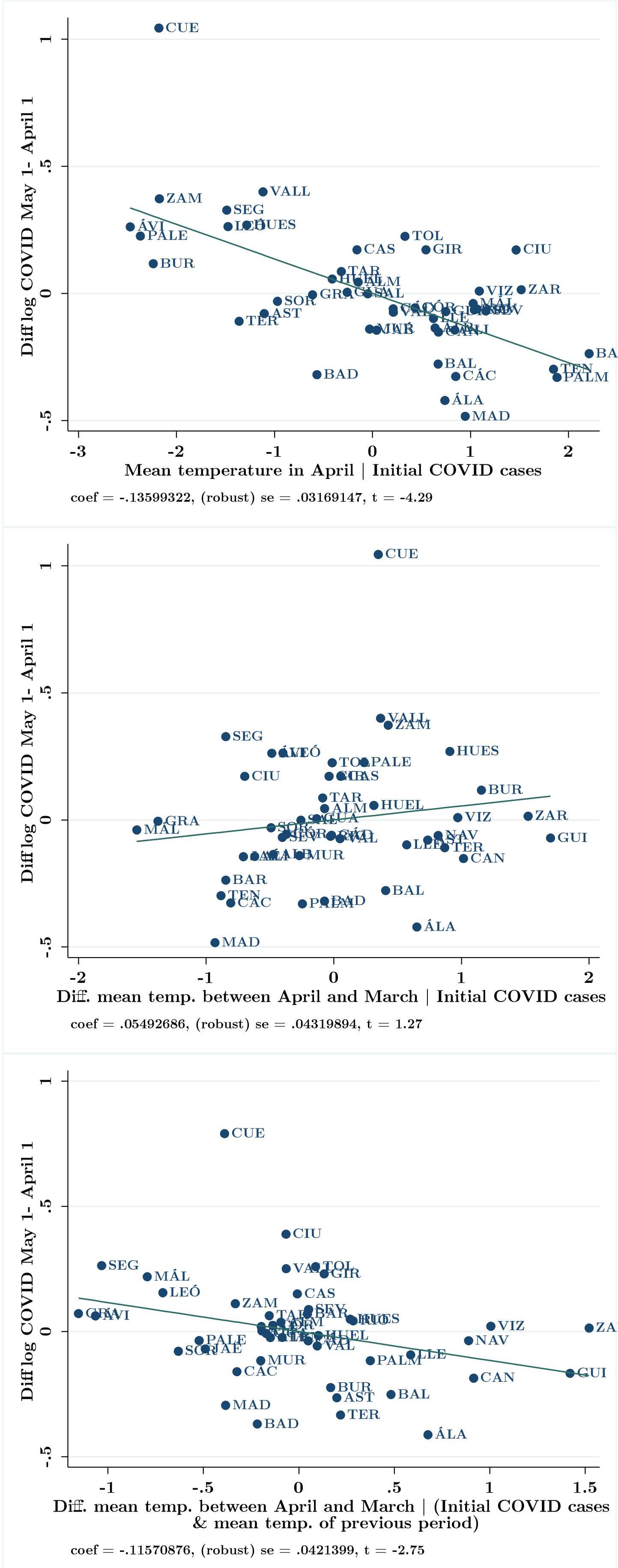
The middle part of Table 11 reports results from regressions of changes in COVID cases on *changes* in temperature, controlling for initial cases. In contrast to previous results, there is no relationship between *changes* in temperature and new COVID-19 cases, no matter if temperature is temporarily lagged or not. This suggests that there is no relationship *within provinces* between temperature and COVID cases. In other words, provinces that have experienced a larger increase in temperature do not tend to have had a *lower* increase in COVID cases.

The bottom part of the table adds average temperature in the previous period to control for "initial" temperature -in the same way as I control for initial cases. The new variable enters with a large and statistically significant negative coefficient, leading to a large increase in R^2. This suggests that it is a relevant variable for the model. Once this variable has been added, changes in temperature are now negatively related to changes in COVID cases. The negative coefficient is more robust when temperature variables are lagged 10 days. Regarding the interpretation of the relationship, according to column 9 (Panel A), one Celsius degree increase in temperature (regarding the previous period) is associated with a 11% reduction in the rate of new cases. Figure 7 represents the conditional correlations between temperature and changes in COVID cases reported in columns 1, 5 and 9 in Panel A.

Therefore, the existence or not of a relationship between temperature and COVID cases depends on the specific model selected. Concerning the lack of a robust correlation between new COVID cases and *changes* in temperature, it may be due to the fact that the existing variation across provinces is larger than within provinces. For instance, the range in values of mean temperature in April is 7.9 while the range of the change in temperature between April and March is 3.7 (i.e., less than half). Therefore, although the evidence is inconclusive regarding the link between changes in temperature and new COVID-19 cases, this arguably does not rule out that big changes in temperature as a result of the summer heat may hinder the spread of the virus.[7]

[7] This inconclusive evidence is consistent with Briz-Redón and Serrano-Aroca (2020) who find no relationship between temperature and COVID incidence in another study of Spanish provinces.

Fig. 7: Changes in COVID cases vs changes in temperature



2.5. The rate of deaths related to COVID-19

I have replicated Tables 1 to 5 using as dependent variable the rate of deaths related to COVID-19 over 100,000 inhabitants on April 1. The results, reported in the Appendix, are similar to the ones in Tables 1 to 5, particularly concerning geographic and meteorological variables. This does not come as a surprise as COVID cases and deaths are highly correlated (p=0.9).[8]

3. Conclusions

This short paper conducts a correlational analysis between the incidence of COVID-19 and a wide range of meteorological, geographic, and socioeconomic variables. While correlations with socioeconomic variables are not stable across specifications and are sometimes counter-intuitive, the correlations with temperature and distance to Madrid, both negative, are more interesting. The one with temperature is particularly robust. Temperature (in levels) is negatively related both to COVID cases and to changes in COVID cases. However, the evidence on the correlation between *changes* in temperature and changes in COVID cases is inconclusive, which casts doubts on the role that the arrival of the summer heat may play in limiting the spread of the virus. This ambiguous result is in line with the view of experts in the field, who point out that the heat, while it may reduce the efficiency with which it is transmitted, will not necessarily stop the coronavirus (EL PAÍS, 2O2O). More data (over a longer period of time) will help assess the real relationship between temperature and COVID-19 cases.

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[8] The data used in the analysis is available at sites.google.com/site/danielotoperalias/research/others

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TABLES

Table 1

	Depedent variable: Log of accumulated cases of COVID19/100000 inhab. on April 1, 2020												
												Step-wise	Step-wise w/o Canarias
	1	2	3	4	5	6	7	8	9	10	11	12	13
MEAN TEMPERAT.	-0.236***									-0.238**	-0.218***	-0.236***	-0.228***
FEB-MAR 20	(0.029)									(0.108)	(0.041)	(0.029)	(0.037)
LATITUDE		0.13***								-0.023			
		(0.028)								(0.078)			
LONGITUDE			0.053**							0.016			
			(0.023)							(0.023)			
MEAN PRECIP. FEB-				-0.029						0.137	0.116		
MAR 20				(0.127)						(0.143)	(0.146)		
AVERAGE					0.001***					0	0		
ALTITUDE					(0)					(0.001)	(0.001)		
COEF. VAR.						-1.039***				0.054	0.098		
ALTITUDE										(0.399)	(0.396)		
ISLAND==1							-0.943***			0.491	0.515		
							(0.248)			(0.549)	(0.388)		
COAST==1								-0.769***		-0.168	-0.162		
								(0.179)		(0.211)	(0.231)		
LN DIST. TO									-0.658***	-0.172*	-0.186**		-0.186**
MADRID									(0.123)	(0.097)	(0.084)		(0.07)
R2	0.59	0.3	0.07	0	0.24	0.24	0.09	0.27	0.29	0.63	0.63	0.59	0.59
Obs	50	50	50	50	50	50	50	50	49	50	50	50	48

Notes: Variables' definitions and sources are available in Table A1. An intercept is included but not reported. Robust standard errors are in parenthesis. *, ** and *** denote statistical significance at the 10, 5 and 1%.

Table 2

	Depedent variable: Log of accumulated cases of COVID19/100000 inhab. on April 1, 2020												
										Canarias excluded	Canarias and Madrid excluded	CCAA fixed effects	CCAA fixed effects - clustered
	1	2	3	4	5	6	7	8	9	10	11	12	13
MEAN TEMPERAT.	-0.236***	-0.256***	-0.235***	-0.237***	-0.235***	-0.23***	-0.246***	-0.224***	-0.211***	-0.256***	-0.25***	-0.194**	-0.194**
FEB-MAR 20	(0.029)	(0.047)	(0.031)	(0.029)	(0.034)	(0.032)	(0.033)	(0.03)	(0.035)	(0.034)	(0.034)	(0.094)	(0.085)
LATITUDE		-0.02											
		(0.031)											
LONGITUDE			0.004										
			(0.02)										
MEAN PRECIP. FEB-				0.036									
MAR 20				(0.076)									
AVERAGE					0								
ALTITUDE					(0)								
COEF. VAR.						-0.072							
ALTITUDE						(0.189)							
ISLAND==1							0.208						
							(0.27)						
COAST==1								-0.096					
								(0.136)					
LN DIST. TO									-0.135				
MADRID									(0.093)				
R2	0.59	0.6	0.59	0.6	0.59	0.59	0.6	0.6	0.61	0.57	0.57	0.75	0.75
Obs	50	50	50	50	50	50	50	50	50	48	47	50	50

Notes: Variables' definitions and sources are available in Table A1. Robust standard errors are in parenthesis, except in column 13, which reports standard errors clustered at the autonomous community level. An intercept is included but not reported. *, ** and *** denote statistical significance at the 10, 5 and 1%.

Table 3

Depedent variable: Log of accumulated cases of COVID19/100000 inhab. on April 1, 2020					
		Madrid excluded	Canarias excluded	Canarias and Madrid excluded	Canarias and Madrid excluded
	1	2	3	4	5
LN DIST. TO MADRID	-0.514***	-0.658***	-0.497***	-0.709***	-0.087
	(0.104)	(0.123)	(0.122)	(0.178)	(0.145)
MEAN TEMPERAT. FEB-MAR 20					-0.239***
					(0.039)
R2	0.3	0.29	0.24	0.23	0.57
Obs	50	49	48	47	47

Notes: Variables' definitions and sources are available in Table A1. An intercept is included but not reported. Robust standard errors are in parenthesis. *, ** and *** denote statistical significance at the 10, 5 and 1%.

Table 4

	Depedent variable: Log of accumulated cases of COVID19/100000 inhab. on April 1, 2020											
	1	2	3	4	5	6	7	8	9	10	11	12
LOG POPUL. 2019	-0.246											
	(0.159)											
LOG POP. DENSITY. 2019		-0.145										
		(0.104)										
LOG GDP pc 2017			1.702***									
			(0.419)									
POP. CONCENTR. 2019				0.021***								
				(0.006)								
AVERAGE PM 2.5µm					-0.042							
					(0.026)							
AVERAGE PM 10µm						-0.048**						
						(0.021)						
POPUL.> 64 (%)							0.068**					
							(0.026)					
AGRIC. EMPL. (%) 2017								-0.037*				
								(0.02)				
INDUST. EMPL. (%) 2017									0.064***			
									(0.018)			
COMM. REST. HOTELS (%)										-0.075***		
										(0.016)		
LOG PASSANGERS Feb-Mar											-0.031*	
											(0.018)	
LOG PASSANG./POP. Feb-Mar												-0.631**
												(0.291)
R2	0.09	0.05	0.21	0.11	0.05	0.1	0.14	0.07	0.21	0.21	0.06	0.07
Obs	50	50	50	50	45	50	50	50	50	50	50	50

Notes: Variables' definitions and sources are available in Table A1. An intercept is included but not reported. Robust standard errors are in parenthesis. *, ** and *** denote statistical significance at the 10, 5 and 1%.

Table 5

Depedent variable: Log of accumulated cases of COVID19/100000 inhab. on April 1, 2020				
		Stepwise	+ Temp.	+ Temp. - Stepwise
	1	2	3	4
LOG POPUL. 2019	0.042		0.045	
	(0.265)		(0.199)	
LOG POP. DENSITY.	-0.048		0.271*	0.212***
2019	(0.21)		(0.141)	(0.067)
LOG GDP pc 2017	1.528**	1.455***	-0.338	
	(0.666)	(0.424)	(0.423)	
POP. CONCENTR.	0.006		0.001	
2019	(0.008)		(0.006)	
AVERAGE PM 10µm	0.004		0.001	
	(0.023)		(0.018)	
POPUL.> 64 (%)	0.037	0.04*	-0.025	
	(0.027)	(0.024)	(0.02)	
AGRIC. EMPL. (%)				
2017				
INDUST. EMPL. (%)	0		0.005	
2017	(0.037)		(0.02)	
COMM. REST.	-0.037	-0.051***	0.01	
HOTELS (%)	(0.035)	(0.017)	(0.024)	
LOG PASSANGERS	-0.014		-0.019	
Feb-Mar	(0.034)		(0.021)	
MEAN TEMPERAT.			-0.345***	-0.295***
FEB-MAR 20			(0.053)	(0.03)
R2	0.42	0.41	0.69	0.67
Obs	50	50	50	50

Notes: Variables' definitions and sources are available in Table A1. An intercept is included but not reported. Robust standard errors are in parenthesis. *, ** and *** denote statistical significance at the 10, 5 and 1%.

Table 6

	Depedent variable: Log of accumulated cases of COVID19/100000 inhab. on March 15, 2020												
												Step-wise	Step-wise w/o Canarias
	1	2	3	4	5	6	7	8	9	10	11	12	13
MEAN TEMPERAT.	-0.153***									-0.141	-0.101		
FEB 1- MAR 15. 20	(0.056)									(0.27)	(0.11)		
LATITUDE		0.081**								-0.112			
		(0.037)								(0.194)			
LONGITUDE			0.047*							0.069			
			(0.028)							(0.063)			
MEAN PRECIP. FEB				0.055						0.236	0.038		
1- MAR 15. 20				(0.097)						(0.234)	(0.144)		
AVERAGE					0.001**					-0.001	0		
ALTITUDE					(0)					(0.001)	(0.001)		
COEF. VAR.						-0.793**				-0.027	0.099		
ALTITUDE										(0.785)	(0.798)		
ISLAND==1							-0.494*			0.638	0.828		
							(0.253)			(0.984)	(0.576)		
COAST==1								-0.621**		-0.333	-0.244		
								(0.254)		(0.456)	(0.429)		
LN DIST. TO									-0.468***	-0.502**	-0.52***	-0.542***	-0.627***
MADRID									(0.163)	(0.198)	(0.173)	(0.105)	(0.104)
R2	0.15	0.07	0.03	0.00	0.06	0.08	0.01	0.10	0.09	0.27	0.25	0.19	0.20
Obs	50	50	50	50	50	50	50	50	49	50	50	50	48

Notes: Variables' definitions and sources are available in Table A1. Robust standard errors are in parenthesis.

Table 7

	Depedent variable: Log of accumulated cases of COVID19/100000 inhab. on March 15, 2020												
										Canarias excluded	Canarias and Madrid excluded	CCAA fixed effects	CCAA fixed effects - clustered SEs
	1	2	3	4	5	6	7	8	9	10	11	12	13
MEAN TEMPERAT.	-0.153***	-0.192**	-0.145**	-0.16***	-0.144**	-0.133**	-0.167**	-0.12**	-0.081	-0.18**	-0.167**	-0.162	-0.162
FEB 1- MAR 15. 20	(0.056)	(0.089)	(0.058)	(0.059)	(0.067)	(0.059)	(0.066)	(0.058)	(0.075)	(0.07)	(0.07)	(0.216)	(0.233)
LATITUDE		-0.038											
		(0.049)											
LONGITUDE			0.018										
			(0.032)										
MEAN PRECIP. FEB				-0.054									
1- MAR 15. 20				(0.084)									
AVERAGE					0								
ALTITUDE					(0)								
COEF. VAR.						-0.247							
ALTITUDE						(0.281)							
ISLAND==1							0.298						
							(0.406)						
COAST==1								-0.262					
								(0.239)					
LN DIST. TO									-0.4**				
MADRID									(0.185)				
R2	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.16	0.22	0.15	0.14	0.57	0.57
Obs	50	50	50	50	50	50	50	50	50	48	47	50	50

Notes: Variables' definitions and sources are available in Table A1. Robust standard errors are in parenthesis, except in column 13, which reports standard errors clustered at the autonomous community level.

Table 8

Depedent variable: Log of accumulated cases of COVID19/100000 inhab. on March 15, 2020					
		Madrid excluded	Canarias excluded	Canarias and Madrid excluded	Canarias and Madrid excluded
	1	2	3	4	5
LN DIST. TO MADRID	-0.542***	-0.468***	-0.627***	-0.609***	-0.293
	(0.105)	(0.163)	(0.104)	(0.225)	(0.293)
MEAN TEMPERAT. FEB 1- MAR 15. 20					-0.133
					(0.087)
R2	0.19	0.09	0.2	0.09	0.16
Obs	50	49	48	47	47

Notes: Variables' definitions and sources are available in Table A1. Robust standard errors are in parenthesis.

Table 9

Depedent variable: Log of accumulated cases of COVID19/100000 inhab. on March 15, 2020												
	1	2	3	4	5	6	7	8	9	10	11	12
LOG POPUL. 2019	0.12											
	(0.173)											
LOG POP. DENSITY. 2019		0.116										
		(0.12)										
LOG GDP pc 2017			1.863**									
			(0.794)									
POP. CONCENTR. 2019				0.028***								
				(0.01)								
AVERAGE PM 2.5µm					-0.044							
					(0.042)							
AVERAGE PM 10µm						0.004						
						(0.029)						
POPUL.> 64 (%)							-0.007					
							(0.03)					
AGRIC. EMPL. (%) 2017								-0.083***				
								(0.023)				
INDUST. EMPL. (%) 2017									0.06*			
									(0.032)			
COMM. REST. HOTELS (%)										-0.041		
										(0.03)		
LOG PASSANGERS Feb-											0.024	
											(0.022)	
LOG PASS./POP. Feb-Mar												0.092
												(0.424)
R2	0.01	0.02	0.14	0.11	0.02	0	0	0.21	0.11	0.04	0.02	0
Obs	50	50	50	50	45	50	50	50	50	50	50	50

Notes: Variables' definitions and sources are available in Table A1. Robust standard errors are in parenthesis.

Table 10

Depedent variable: Log of accumulated cases of COVID19/100000 inhab. March 15, 2020				
		Stepwise	+ Temp.	+ Temp. - Stepwise
	1	2	3	4
LOG POPUL. 2019	0.146		0.175	
	(0.415)		(0.356)	
LOG POP. DENSITY. 2019	-0.083		0.258	0.377***
	(0.353)		(0.318)	(0.119)
LOG GDP pc 2017	1.575	1.863**	-0.741	
	(1.175)	(0.794)	(1.067)	
POP. CONCENTR. 2019	0.009		0.004	
	(0.012)		(0.009)	
AVERAGE PM 10µm	0.038		0.029	
	(0.031)		(0.027)	
POPUL.> 64 (%)	0.005		-0.079**	-0.094***
	(0.038)		(0.032)	(0.033)
AGRIC. EMPL. (%) 2017				
INDUST. EMPL. (%) 2017	0.014		0.023	
	(0.052)		(0.034)	
COMM. REST. HOTELS (%)	-0.043		0.02	
	(0.052)		(0.043)	
LOG PASSANGERS Feb-Mar	0.024		0.014	
	(0.048)		(0.034)	
MEAN TEMPERAT. FEB 1- MAR 15. 20			-0.41***	-0.355***
			(0.105)	(0.07)
R2	0.25	0.14	0.46	0.41
Obs	50	50	50	50

Notes: Variables' definitions and sources are available in Table A1. Robust standard errors are in parenthesis.

Tabla 11 - Changes in COVID-19 cases

Dependent variable: difference in the rate of accumulated cases of COVID-19 between two dates

	Panel A: Temperature without lags				*Panel B: Temperature lagged 10 days*			
	Difference between May 1 and April 1	Difference between April 1 and March 15	Difference between April 15 and April 1	Difference between May 1 and April 15	Difference between May 1 and April 1	Difference between April 1 and March 15	Difference between April 15 and April 1	Difference between May 1 and April 15
	1	2	3	4	1	2	3	4
Log. accumulated case rate at the beginning of the period	-0.126	-0.65***	-0.042	-0.017	-0.135*	-0.633***	-0.04	-0.066**
	(0.076)	(0.049)	(0.059)	(0.029)	(0.077)	(0.051)	(0.055)	(0.031)
Average temperature during the indicated period	-0.136***	-0.179***	-0.062**	-0.041***	-0.137***	-0.189***	-0.048***	-0.073***
	(0.032)	(0.026)	(0.024)	(0.012)	(0.031)	(0.028)	(0.017)	(0.014)
R^2	0.47	0.76	0.26	0.25	0.48	0.75	0.25	0.39
N	46	50	46	46	46	50	46	46
	5	6	7	8	5	6	7	8
Log. accumulated case rate at the beginning of the period	0.073	-0.462***	0.02	0.055***	0.105*	-0.458***	0.07**	0.047*
	(0.062)	(0.068)	(0.048)	(0.019)	(0.055)	(0.066)	(0.034)	(0.026)
Difference between mean temperature in the indicated period and that of the previous period	0.055	-0.004	0.059	0.012	0.015	0.14**	-0.029	0.016
	(0.043)	(0.056)	(0.035)	(0.018)	(0.032)	(0.054)	(0.019)	(0.024)
R^2	0.12	0.43	0.13	0.11	0.1	0.5	0.11	0.11
N	46	50	46	46	46	50	46	46
	9	10	11	12	9	10	11	12
Log. accumulated case rate at the beginning of the period	-0.137	-0.647***	-0.07	-0.068**	-0.143*	-0.621***	-0.041	-0.067*
	(0.085)	(0.05)	(0.067)	(0.033)	(0.083)	(0.048)	(0.065)	(0.033)
Difference between mean temperature in the indicated period and that in the previous period	-0.116***	-0.129**	-0.016	-0.011	-0.124***	-0.092*	-0.047**	-0.069***
	(0.042)	(0.048)	(0.028)	(0.014)	(0.038)	(0.051)	(0.017)	(0.025)
Mean temperature in the previous period	-0.134***	-0.185***	-0.058**	-0.071***	-0.137***	-0.179***	-0.049**	-0.073***
	(0.031)	(0.026)	(0.023)	(0.015)	(0.032)	(0.027)	(0.021)	(0.014)
R^2	0.47	0.77	0.29	0.4	0.49	0.77	0.25	0.4
N	46	50	46	46	46	50	46	46

Notes: The dependent variable is the difference in the log. of accumulated cases of COVID-19 per 100,000 inhab. between the two dates indicated in each heading. The variable "difference between mean temperature in the indicated period and that of the previous period" refers, in column 5, to the difference in average temperature between April and March; in column 6, the difference between the second and first fortnight of March, etc. The variable "mean temperature in the previous period" refers, in column 9, to the average of March; in column 10, of the first fortnight of March, etc. In Panel B, all temperature variables are calculated with a 10-day lag (for example, when temperature refers to the month of April, it is actually calculated for the period from March 20 to April 20). Robust standard errors appear in parentheses. *, **, *** indicates that the coefficient is statistically significant at 10, 5 and 1%, respectively.

Table A1: Description of variables and sources

Variable name	Description	Source
CASES COVID-19	Accumulated confirmed cases of COVID-19 over 100,000 inhabitants.	Escovid19data at https://github.com/montera34/escovid19data
DEATHS COVID-19	Accumulated confirmed deaths related to COVID-19 over 100,000 inhabitants.	Escovid19data at https://github.com/montera34/escovid19data
MEAN TEMPERATURE	Average of daily mean temperatures during the specified period. Daily mean temperatures are the average between the maximim and minimum temperatures of each day. Provincial values are calculated as the weighted average of available weather stations where weights are the population of the municipality in which a station is located. When lags are included, the variable is constructed with a 10-day lag (for example, when temperature refers to the month of April, it is actually calculated for the period from March 20 to April 20).	Own elaboration using data from datosclima.es -Base de datos Meteorológica.
MEAN PRECIPITATION	Average of daily precipitations during the specified period. Provincial values are calculated as the weighted average of available weather stations where weights are the population of the municipality in which a station is located.	Own elaboration using data from datosclima.es -Base de datos Meteorológica.
LATITUDE	Latitude of the centroid of the province.	Own elaboration using GIS.
LONGITUDE	Latitude of the centroid of the province.	Own elaboration using GIS.
AVERAGE ALTITUDE	Average altitude of the province (unweighted average of the municipalities of the province).	Own elaboration using data from Nomenclátor Geográfico de Municipios y Entidades de Población (Instituto Geográfico Nacional).
COEF. VAR. ALTITUDE	Coefficient of variation of the altitude of the municipalities of the province.	Own elaboration using data from Nomenclátor Geográfico de Municipios y Entidades de Población (Instituto Geográfico Nacional).
ISLAND==1	Dummy variable equal to 1 if the province is an island.	Own elaboration.
COAST==1	Dummy variable equal to 1 if the province is coastal.	Own elaboration.
LN DIST. TO MADRID	Natural logarithm of the linear distance between the centroid of the province and Madrid (in 100 km).	Own elaboration using GIS.
PROVINCE NAME	Name of the province.	
AUT. COMMUNITY NAME	Name of the autonomous community.	
LOG POPUL. 2019	Natural logarithm of the total population in 2019	Padrón Municipal. Instituto Nacional de Estadística.
LOG POP. DENSITY. 2019	Natural logarithm of the total population in 2019 divided by surface area.	Own elaboration using data from Padrón Municipal (Instituto Nacional
LOG GDP pc 2017	Natural logarithm of GDP per capita in 2017.	Contabilidad Regional de España (Instituto Nacional de Estadística).

POP. CONCENTR. 2019	Percentage of the population living in the most populated 10% of the territory. It is calculated using municipalities' population and surface area.	Own elaboration using data from Padrón Municipal (Instituto Nacional de Estadística).
POP DENSITY IN 10% MOST POPULATED	Natural logarithm of population density corresponding to the most populated 10% of the territory. It is calculated using municipalities' population and surface area.	Own elaboration using data from Padrón Municipal (Instituto Nacional de Estadística).
AVERAGE PM 2.5µm	Anual average in 2018 of particles lower than 2.5 µm. Provincial values are calculated as the weighted average of available air quality stations where weights are the population of the municipality in which a station is located.	Own elaboration using data from Estaciones de calidad del aire. Infraestructura de Datos Espaciales (Ministerio para la Transición Ecológica y el Reto Demográfico).
AVERAGE PM 10µm	Anual average in 2018 of particles lower than 2.5 µm. Provincial values are calculated as the weighted average of available air quality stations where weights are the population of the municipality in which a station is located.	Own elaboration using data from Estaciones de calidad del aire. Infraestructura de Datos Espaciales (Ministerio para la Transición Ecológica y el Reto Demográfico).
POPUL.> 64 (%)	Percentage of population older than 64 years.	Own elaboration using data from Padrón Municipal (Instituto Nacional de Estadística).
AGRIC. EMPL. (%) 2017	Percentage of workers in the agricultural sector in 2017 (NACE=A)	Contabilidad Regional de España (Instituto Nacional de Estadística).
INDUST. EMPL. (%) 2017	Percentage of workers in the agricultural sector in 2017 (NACE=B-E).	Contabilidad Regional de España (Instituto Nacional de Estadística).
CONST. EMPL. (%) 2017	Percentage of workers in the construction sector in 2017 (NACE=F).	Contabilidad Regional de España (Instituto Nacional de Estadística).
COMM. REST. HOTELS EMP (%)	Percentage of workers in commerce, restaurants and hotels in 2017 (NACE=G-J)	Contabilidad Regional de España (Instituto Nacional de Estadística).
PROF. SERVICES (%) 2017	Percentage of workers in professional services in 2017 (NACE=K-N).	Contabilidad Regional de España (Instituto Nacional de Estadística).
PUBLIC ADMON. EMPL. (%) 2017	Percentage of workers in the public administration in 2017 (NACE=O-U).	Contabilidad Regional de España (Instituto Nacional de Estadística).
LOG PASSANG./POP. Feb-Mar	One plus the natural logarithm of airline passengers over total population during February and March of 2020.	Estadística de tráfico de pasajeros, operaciones y carga en los aeropuertos españoles (AENA)
LOG PASSANGERS Feb-Mar	One plus the natural logarithm of airline passengers during February and March of 2020.	Estadística de tráfico de pasajeros, operaciones y carga en los aeropuertos españoles (AENA)

Table A2 - Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
CASES COVID-19 on March 15	50	16.695	24.627	1.150	123.360
CASES COVID-19 on April 1	50	236.358	179.390	40.460	743.490
CASES COVID-19 on April 15	46	430.834	341.554	55.690	1373.350
CASES COVID-19 on May 1	46	602.689	487.436	62.480	1960.830
DEATHS COVID-19 on March 15	46	0.407	0.875	0.000	4.830
DEATHS COVID-19 on April 1	50	18.147	16.640	1.150	62.660
DEATHS COVID-19 on April 15	50	39.633	32.657	2.770	132.930
DEATHS COVID-19 on May 1	46	56.953	43.447	3.480	197.470
MEAN TEMPERATURE JANUARY	50	8.416	3.019	3.969	16.835
MEAN TEMP. FEBRUARY	50	11.972	2.503	8.175	19.290
MEAN TEMP 1 - 15 FEB	50	12.207	2.533	8.333	19.491
MEAN TEMP 16 - 29 FEB	50	11.721	2.516	8.005	19.076
MEAN TEMP MARCH	50	11.921	2.354	7.888	17.639
MEAN TEMP 1- 15 MARCH	50	13.206	2.462	9.065	18.747
MEAN TEMP 16-31 MARCH	50	10.957	2.415	6.443	16.809
MEAN TEMP APRIL	50	14.446	1.753	11.015	18.892
MEAN TEMP 1- 15 APRIL	50	13.903	1.763	10.762	19.291
MEAN TEMP 16-30 APRIL	50	14.989	1.923	11.113	18.492
MEAN TEMP. FEBRUARY - 10 DAYS L	50	11.881	2.558	7.977	19.035
MEAN TEMP 1 - 15 FEB - 10 DAYS LA	50	13.476	2.593	9.701	20.728
MEAN TEMP 16 - 29 FEB - 10 DAYS L/	50	11.382	2.573	7.439	18.506
MEAN TEMP MARCH - 10 DAYS LAG	50	12.733	2.277	8.840	18.114
MEAN TEMP 1- 15 MARCH - 10 DAYS	50	12.716	2.716	8.234	18.639
MEAN TEMP 16-31 MARCH - 10 DAYS	50	12.738	2.215	8.689	17.964
MEAN TEMP APRIL - 10 DAYS LAG	50	14.133	1.786	10.679	19.097
MEAN TEMP 1- 15 APRIL - 10 DAYS L/	50	12.006	2.241	7.835	18.776
MEAN TEMP 16-30 APRIL - 10 DAYS L/	50	14.798	1.689	11.441	19.197
MEAN DAILY PRECIPITATION JANUA	50	1.888	1.485	0.089	6.954
MEAN DAILY PREC. FEBRUARY	50	0.342	0.655	0.001	2.846
MEAN DAILY PREC 1 - 15 FEB	50	0.225	0.367	0.001	1.946
MEAN DAILY PREC 16 - 29 FEB	50	0.467	0.993	0.000	4.202
MEAN DAILY PREC MARCH	50	2.419	1.037	0.783	4.853
MEAN DAILY PREC 1- 15 MARCH	50	1.578	1.858	0.012	6.529
MEAN DAILY PREC 16-31 MARCH	50	3.036	1.916	0.215	7.670
MEAN DAILY PREC APRIL	50	2.615	1.300	0.225	7.016
MEAN DAILY PREC 1- 15 APRIL	50	2.641	1.213	0.094	6.061

MEAN DAILY PREC 16-30 APRIL	50	2.579	2.066	0.000	11.337
MEAN DAILY PREC. FEBRUARY - 10 I	50	0.269	0.477	0.002	2.470
MEAN DAILY PREC 1 - 15 FEB - 10 D/	50	0.200	0.345	0.000	1.600
MEAN DAILY PREC 16 - 29 FEB - 10 D	50	0.290	0.536	0.000	2.781
MEAN DAILY PREC MARCH - 10 DAY	50	2.368	1.457	0.297	6.798
MEAN DAILY PREC 1- 15 MARCH - 10	50	3.502	4.269	0.000	15.984
MEAN DAILY PREC 16-31 MARCH - 1(	50	2.035	1.184	0.204	5.488
MEAN DAILY PREC APRIL - 10 DAYS I	50	3.052	1.576	0.265	8.812
MEAN DAILY PREC 1- 15 APRIL - 10 D	50	2.315	2.304	0.005	15.257
MEAN DAILY PREC 16-30 APRIL - 10 D	50	3.260	1.908	0.076	10.756
LATITUDE	50	40.123	3.136	28.303	43.295
LONGITUDE	50	-3.823	3.694	-17.023	2.908
AVERAGE ALTITUDE	50	534.898	276.038	111.009	1044.142
COEF. VAR. ALTITUDE	50	0.523	0.345	0.060	1.355
ISLAND==1	50	0.060	0.240	0.000	1.000
COAST==1	50	0.440	0.501	0.000	1.000
LN DIST. TO MADRID	50	12.537	0.782	8.911	14.412
LOG POPUL. 2019	50	13.312	0.901	11.392	15.712
LOG POP. DENSITY. 2019	50	-0.381	1.152	-2.453	2.117
LOG GDP pc 2017	50	10.042	0.198	9.754	10.517
POP. CONCENTR. 2019	50	64.732	11.843	40.616	85.402
POP DENSITY IN 10% MOST POPULAT	50	6.019	1.193	3.864	8.634
AVERAGE PM 2.5µm	45	11.044	3.552	4.300	19.535
AVERAGE PM 10µm	50	19.912	4.977	12.000	29.418
POPUL.> 64 (%)	50	21.007	4.060	14.727	31.381
AGRIC. EMPL. (%) 2017	50	7.119	5.335	0.129	26.076
INDUST. EMPL. (%) 2017	50	12.661	5.332	4.455	25.919
CONST. EMPL. (%) 2017	50	6.376	1.386	2.679	9.984
COMM. REST. HOTELS EMP (%)	50	30.751	4.514	22.804	46.237
PROF. SERVICES (%) 2017	50	11.917	2.996	7.098	22.820
PUBLIC ADMON. EMPL. (%) 2017	50	31.175	3.192	21.591	38.192
LOG PASSANG./POP. Feb-Mar	50	0.167	0.316	0.000	1.367
LOG PASSANGERS Feb-Mar	50	7.257	5.790	0.000	15.667
TOTAL POPULATION 2019	50	937099	1200404	88636	6663394
GDP 2017	50	23200000	37200000	2192878	221000000
SURFACE AREA SQ-KM	50	1009341	480614	190904	2176628

Appendix. Results for deaths related to COVID-19

Table A1

	Depedent variable: Log of accumulated deaths related to COVID19/100000 inhab. on April 1, 2020												
												Step-wise	Step-wise w/o Canarias
	1	2	3	4	5	6	7	8	9	10	11	12	13
MEAN TEMPERAT. FEB-MAR 20	-0.331***									-0.326**	-0.243***	-0.21***	-0.292***
	(0.038)									(0.143)	(0.061)	(0.051)	(0.047)
LATITUDE		0.145***								-0.092			
		(0.035)								(0.108)			
LONGITUDE			0.094***							0.06*			
			(0.03)							(0.032)			
MEAN PRECIP. FEB-MAR 20				-0.361*						-0.014	-0.093		
				(0.185)						(0.167)	(0.195)		
AVERAGE ALTITUDE					0.002***					0	0.001	0.001**	
					(0)					(0.001)	(0.001)	(0)	
COEF. VAR. ALTITUDE						-1.849***				0.017	0.186		
										(0.613)	(0.671)		
ISLAND==1							-1.227***			0.476	0.597		
							(0.292)			(0.855)	(0.519)		
COAST==1								-1.242***		-0.063	-0.048		
								(0.246)		(0.324)	(0.361)		
LN DIST. TO MADRID									-1.156***	-0.332***	-0.384***	-0.307***	-0.492***
									(0.183)	(0.097)	(0.102)	(0.103)	(0.133)
R2	0.55	0.18	0.11	0.06	0.42	0.36	0.08	0.34	0.42	0.68	0.65	0.64	0.63
Obs	50	50	50	50	50	50	50	50	49	50	50	50	48

Notes: Variables' definitions and sources are available in Table A1. Robust standard errors are in parenthesis.

Table A2

	Depedent variable: Log of accumulated deaths related to COVID19/100000 inhab. on April 1, 2020												
										Canarias excluded	Canarias and Madrid excluded	CCAA fixed effects	CCAA fixed effects - clustered
	1	2	3	4	5	6	7	8	9	10	11	12	13
MEAN TEMPERAT. FEB-MAR 20	-0.331***	-0.443***	-0.317***	-0.324***	-0.249***	-0.268***	-0.35***	-0.277***	-0.256***	-0.366***	-0.358***	-0.225*	-0.225*
	(0.038)	(0.063)	(0.041)	(0.038)	(0.043)	(0.046)	(0.044)	(0.051)	(0.044)	(0.045)	(0.044)	(0.122)	(0.112)
LATITUDE		-0.113***											
		(0.042)											
LONGITUDE			0.028										
			(0.034)										
MEAN PRECIP. FEB-MAR 20				-0.272**									
				(0.124)									
AVERAGE ALTITUDE					0.001***								
					(0)								
COEF. VAR. ALTITUDE						-0.724*							
						(0.367)							
ISLAND==1							0.407						
							(0.418)						
COAST==1								-0.411					
								(0.274)					
LN DIST. TO MADRID									-0.392***				
									(0.109)				
R2	0.55	0.6	0.56	0.59	0.6	0.59	0.56	0.58	0.61	0.54	0.54	0.8	0.8
Obs	50	50	50	50	50	50	50	50	50	48	47	50	50

Notes: Variables' definitions and sources are available in Table A1. Robust standard errors are in parenthesis, except in column 13, which reports standard errors clustered at the autonomous community level..

Table A3

Depedent variable: Log of accumulated deaths related to COVID19/100000 inhab. on April 1, 2020					
			Canarias excluded	Canarias and Madrid excluded	Canarias and Madrid excluded
	1	2	3	4	5
LN DIST. TO MADRID	-0.851***	-1.156***	-0.891***	-1.426***	-0.739***
	(0.191)	(0.183)	(0.26)	(0.236)	(0.235)
MEAN TEMPERAT. FEB-MAR 20					-0.264***
					(0.052)
R2	0.39	0.42	0.35	0.42	0.62
Obs	50	49	48	47	47

Notes: Variables' definitions and sources are available in Table A1. Robust standard errors are in parenthesis.

Table A4

Depedent variable: Log of accumulated deaths related to COVID19/100000 inhab. on April 1, 2020

	1	2	3	4	5	6	7	8	9	10	11	12
LOG POPUL. 2019	-0.383*											
	(0.225)											
LOG POP. DENSITY. 2019		-0.293*										
		(0.149)										
LOG GDP pc 2017			1.898***									
			(0.645)									
POP. CONCENTR. 2019				0.031***								
				(0.009)								
AVERAGE PM 2.5μm					-0.076*							
					(0.039)							
AVERAGE PM 10μm						-0.052						
						(0.032)						
POPUL.> 64 (%)							0.076*					
							(0.042)					
AGRIC. EMPL. (%) 2017								-0.041				
								(0.029)				
INDUST. EMPL. (%) 2017									0.065**			
									(0.024)			
COMM. REST. HOTELS (%)										-0.088***		
										(0.021)		
LOG PASSANGERS Feb-Mar											-0.055**	
											(0.027)	
LOG PASSANG./POP. Feb-Mar												-0.829**
												(0.388)
R2	0.1	0.1	0.12	0.12	0.07	0.06	0.08	0.04	0.1	0.14	0.09	0.06
Obs	50	50	50	50	45	50	50	50	50	50	50	50

Notes: Variables' definitions and sources are available in Table A1. Robust standard errors are in parenthesis, except in column 13, which reports standard errors clustered at the autonomous community level..

Table A5

Depedent variable: Log of accumulated deaths related to COVID19/100000 inhab. on April 1, 2020				
		Stepwise	+ Temp.	+ Temp. - Stepwise
	1	2	3	4
LOG POPUL. 2019	0.264		0.269	
	(0.385)		(0.289)	
LOG POP. DENSITY.	-0.373	-0.385***	0.138	
2019	(0.326)	(0.124)	(0.207)	
LOG GDP pc 2017	2.201*	2.004**	-0.784	
	(1.138)	(0.765)	(0.761)	
POP. CONCENTR.	0.02	0.018*	0.012	
2019	(0.012)	(0.01)	(0.008)	
AVERAGE PM 2.5µm				
AVERAGE PM 10µm	0		-0.004	
	(0.037)		(0.025)	
POPUL.> 64 (%)	0.019		-0.081**	-0.082***
	(0.049)		(0.03)	(0.029)
AGRIC. EMPL. (%)				
2017				
INDUST. EMPL. (%)	-0.016		-0.009	
2017	(0.056)		(0.028)	
COMM. REST.	-0.015		0.059	0.055*
HOTELS (%)	(0.056)		(0.036)	(0.03)
LOG PASSANGERS	-0.035		-0.044	
Feb-Mar	(0.057)		(0.034)	
LOG PASSANG./POP.				
Feb-Mar				
MEAN TEMPERAT.			-0.552***	-0.488***
FEB-MAR 20			(0.078)	(0.063)
R2	0.36	0.33	0.68	0.64
Obs	50	50	50	50

Notes: Variables' definitions and sources are available in Table A1. Robust standard errors are in parenthesis, except in column 13, which reports standard errors clustered at the autonomous community level.